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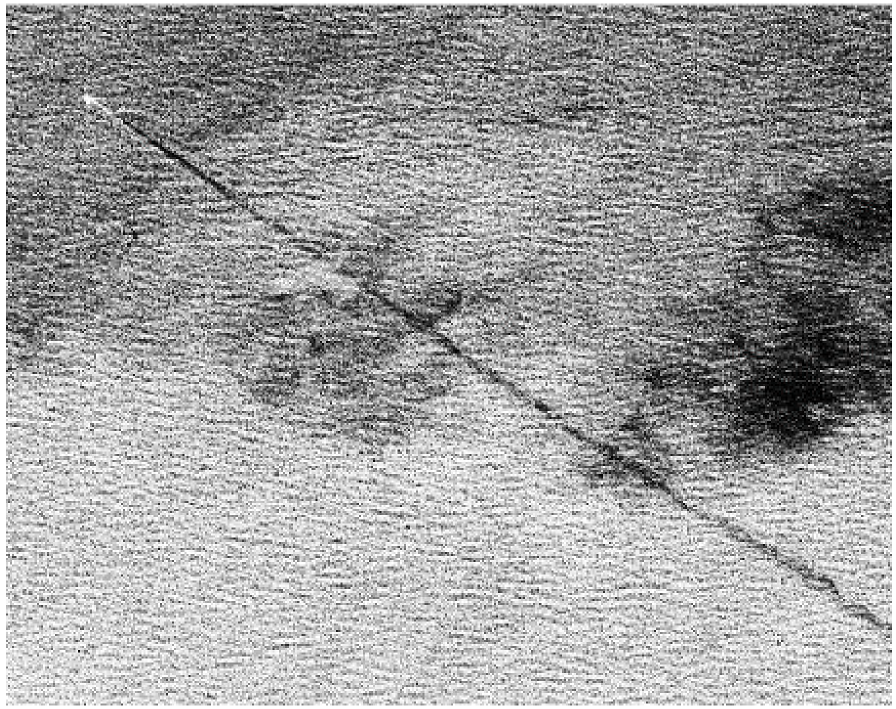

# LINEAR FEATURE DETECTION IN SAR IMAGES

Ph. COURMONTAGNE

L2MP UMR CNRS 6137 / ISEM

L2MP

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

UMR 6137

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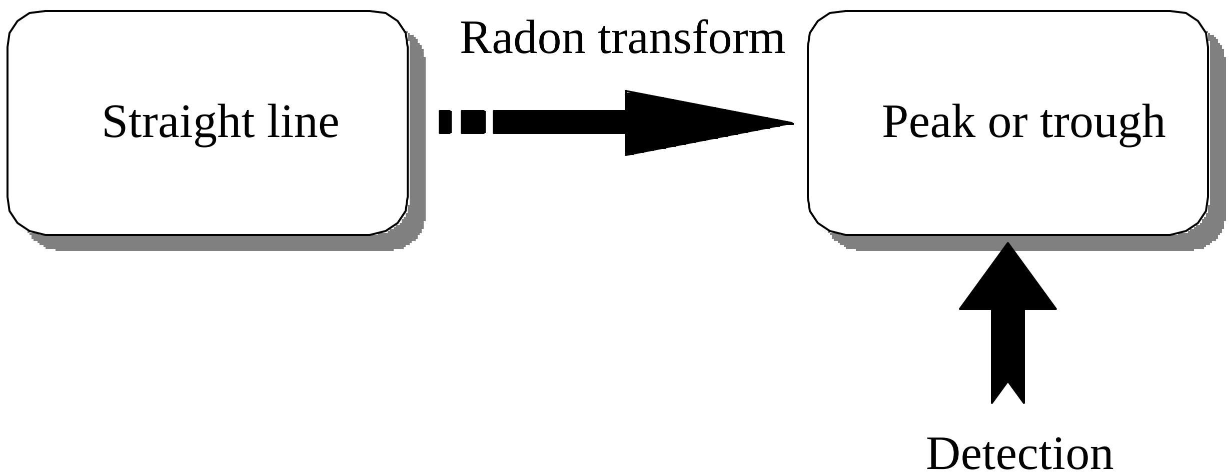
## INTRODUCTION

- Ship wakes in Synthetic Aperture Radar (SAR) images
- Detection using Radon transform (DEANS, 1983)




- SAR images affected by speckle
  - ↳ wedding between the Radon transform and a filtering method

## CONTENTS

- Radon transform
  - discrete form
- Stochastic matched filtering method
- Interpolation-filtering method
  - theory and subimage processing
- Experimental results on SAR images
  - comparison with the classical approach

# LINEAR FEATURE DETECTION IN SAR IMAGES

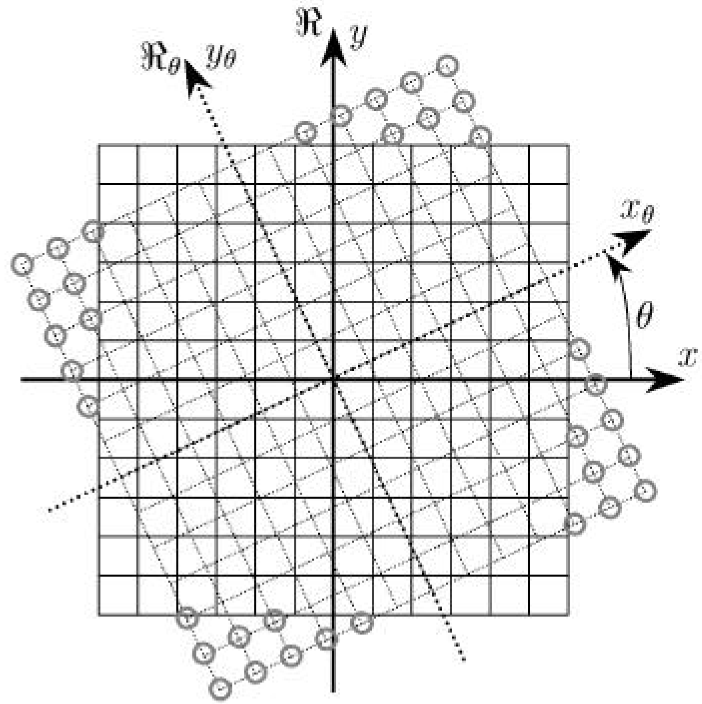
## THE RADON TRANSFORM

❍Consider an image *I*, with dimensions $M \times M$

The Radon transform $\widehat{I}$ of this image is:

$$\widehat{I}(x_\theta, \theta) = \sum_{y_\theta=-M/2}^{M/2} I(x_\theta \cos\theta - y_\theta \sin\theta, x_\theta \sin\theta + y_\theta \cos\theta)$$

where $(x_\theta\ ,\ y_\theta) \in \mathbb{Z}$ and $\theta \in [0;\pi]$




❍Problems : - new pixel coordinates in $\Re \notin \mathbb{Z}^2$

↳ Computation of the new pixel values

- pixels localized at the edge in $\Re_\theta \notin I$ (surrounding points)

↳ Edge effect $\Rightarrow$ size of the image in $\Re_\theta$ : $\frac{M}{\sqrt{2}} \times \frac{M}{\sqrt{2}}$

## STOCHASTIC MATCHED FILTERING METHOD

- Consider the stationary noise-corrupted signal defined over $D$ :

$$Z(x,y) = S(x,y) + B(x,y)$$

where signal $S(x,y)$ and noise $B(x,y)$ are assumed to be independent.

- Observed signal expansion:

$$\widehat{Z}(x,y) = \sum_{n=1}^{Q} z_n \Psi_n(x,y)$$

where:

- $\Psi_n(x,y)$ : deterministic and linearly independent basis functions
- $Q$ : number of basis functions retained for the expansion
- uncorrelated random variables defined by $z_n = \iint_D Z(x,y)\Phi_n(x,y)\,dx\,dy$

# LINEAR FEATURE DETECTION IN SAR IMAGES

❍Determination of functions $\Phi_n(x, y)$

↳Making sure $z_n$ are uncorrelated

↳Optimization of the signal to noise ratio $K$ expressed as a Rayleigh quotient

$\Rightarrow$ $K$ will be maximized if $\Phi_n(x, y)$ are solutions of:

$$\iint_D \Gamma_{SS}(x - x', y - y')\Phi_n(x', y')dx'dy' = \lambda_n \iint_D \Gamma_{BB}(x - x', y - y')\Phi_n(x', y')dx'dy'$$

where $\Gamma_{SS}$ and $\Gamma_{BB}$ are the covariances of the signal and of the noise

❍Determination of functions $\Psi_n(x, y)$

$$\Psi_n(x, y) = \iint_D \Gamma_{BB}(x - x', y - y')\Phi_n(x', y')dx'dy'$$

❍Signal to noise ratio of the $n^{th}$ component of $Z(x, y)$ : $\dfrac{\sigma_S^2}{\sigma_B^2}\lambda_n$

$\Rightarrow$ number $Q$ of basis functions such as $\lambda_Q \geq 1$

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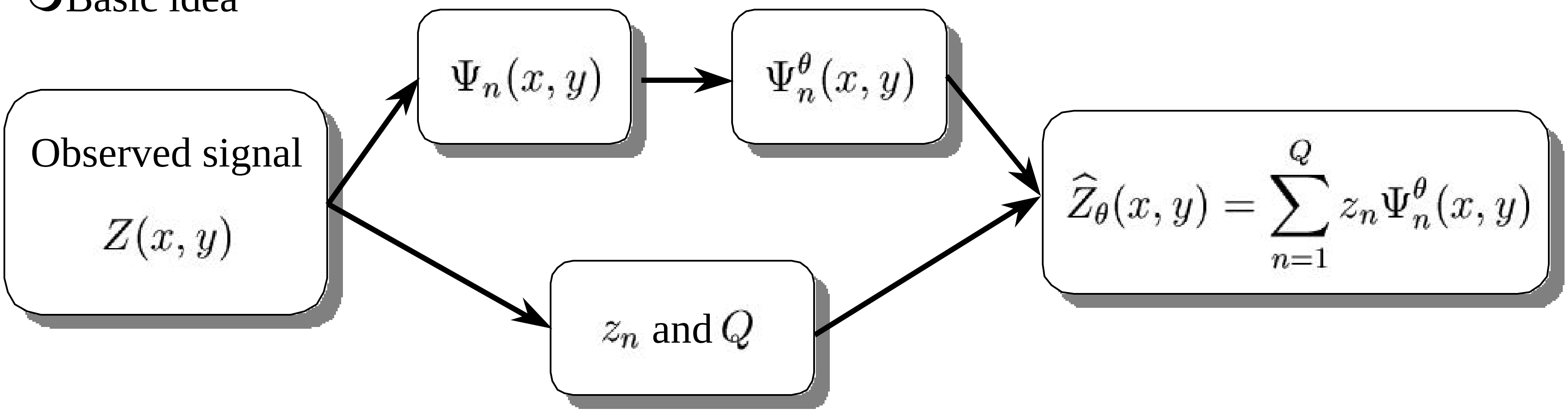
## INTERPOLATION-FILTERING METHOD

❍ Basic idea




↳ Observed signal expansion and restoration using interpolated functions $\Psi_n(x,y)$

❍ Defaults: heavy CPU budget and memory problems

$\Rightarrow$ new formulation using the discrete cosine transform

# LINEAR FEATURE DETECTION IN SAR IMAGES

- $Z(x,y)$ interpolation-filtering using DCT, with $D = [-T;T]^2$

| Functions | DCT coefficients |
|---|---|
| $\Phi_n(x,y)$ | $\alpha^n_{k,l}$ |
| $\Psi_n(x,y)$ | $\beta^n_{p,q}$ |
| $Z(x,y)$ | $\vartheta_{p,q}$ |
| $\widehat{Z}(x,y)$ | $\widehat{\vartheta}_{k,l}$ |
| $\Gamma_{SS}$ | $\Omega^{\Gamma_{SS}}_{k,l,p,q}$ |
| $\Gamma_{BB}$ | $\Omega^{\Gamma_{BB}}_{k,l,p,q}$ |

| | |
|---|---|
| $\Phi_n(x,y) \Longleftrightarrow$ | $\sum_{k=0}^{Nf}\sum_{l=0}^{Nf} \alpha^n_{k,l}\Omega^{\Gamma_{SS}}_{k,l,p,q} = \lambda_n \sum_{k=0}^{Nf}\sum_{l=0}^{Nf} \alpha^n_{k,l}\Omega^{\Gamma_{BB}}_{k,l,p,q}$ |
| $\Psi_n(x,y) \Longleftrightarrow$ | $\beta^n_{p,q} = T^2 \sum_{k=0}^{Nf}\sum_{l=0}^{Nf} \alpha^n_{k,l}\Omega^{\Gamma_{BB}}_{k,l,p,q}$ |
| $z_n \Longleftrightarrow$ | $z_n = T^2 \sum_{p=0}^{Nf}\sum_{q=0}^{Nf} \vartheta_{p,q}\alpha^n_{p,q}$ |
| $\widehat{Z}(x,y) \Longleftrightarrow$ | $\widehat{\vartheta}_{k,l} = \sum_{n=1}^{Q} z_n \beta^n_{k,l}$ |

- Signal of interest restoration in $\Re_\theta$

$$\widehat{Z}_\theta(x_\theta, y_\theta) = \sum_{k=0}^{Nf}\sum_{l=0}^{Nf} \widehat{\vartheta}_{k,l} \cos\left(\frac{\pi k(x_\theta - T)}{2T}\right)\cos\left(\frac{\pi l(y_\theta - T)}{2T}\right)$$

# LINEAR FEATURE DETECTION IN SAR IMAGES

## Subimage processing

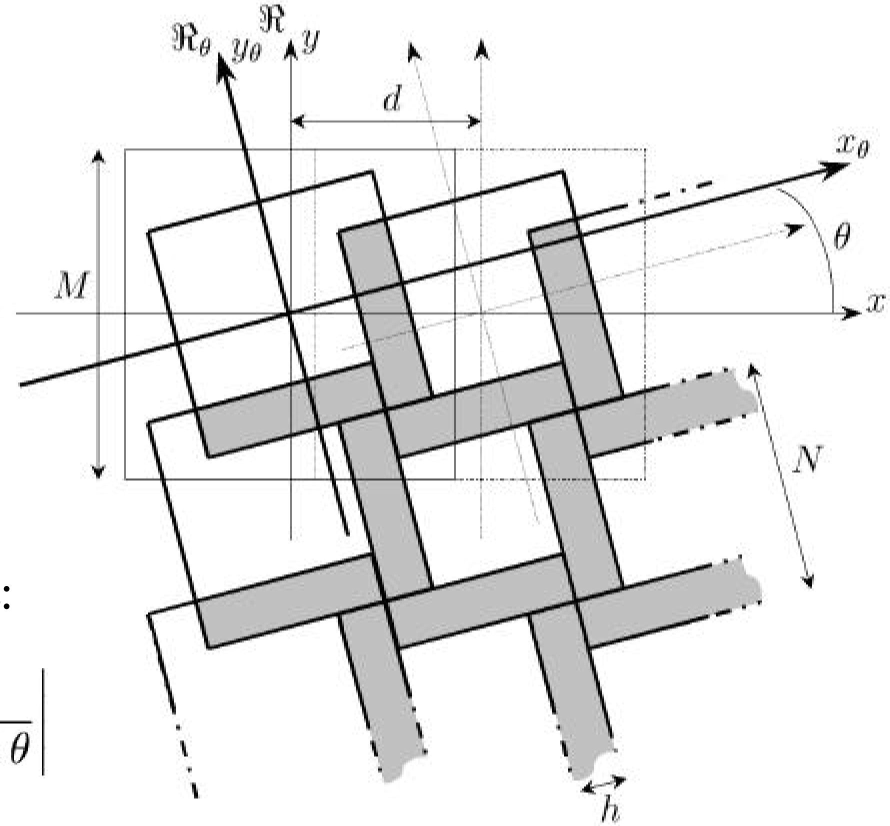
❍Assumption: $Z(x,y)$ is stationary

$\Rightarrow$ necessity of a subimage processing

❍Edge effect

$\Rightarrow$ overlapping between adjacent subimages:

$$d = \frac{N}{\cos\theta + \sin\theta} \quad \text{and} \quad h = \left|\frac{N\sin\theta}{\sin\theta + \cos\theta}\right|$$




❍Smoothing effect when $Q$ is the same for the whole image

$\Rightarrow$ minimization of the mean square error to find $Q$ for each subimage

$$\bar{\epsilon} = \sigma_S^2 + \frac{1}{4}\sum_{n=1}^{Q}\left(\sigma_B^2 - \lambda_n \sigma_S^2\right)\sum_{k=0}^{Nf}\sum_{l=0}^{Nf}\left(\beta_{k,l}^n\right)^2$$

# LINEAR FEATURE DETECTION IN SAR IMAGES

## EXPERIMENTAL RESULTS

❍SIR-C/X-SAR image

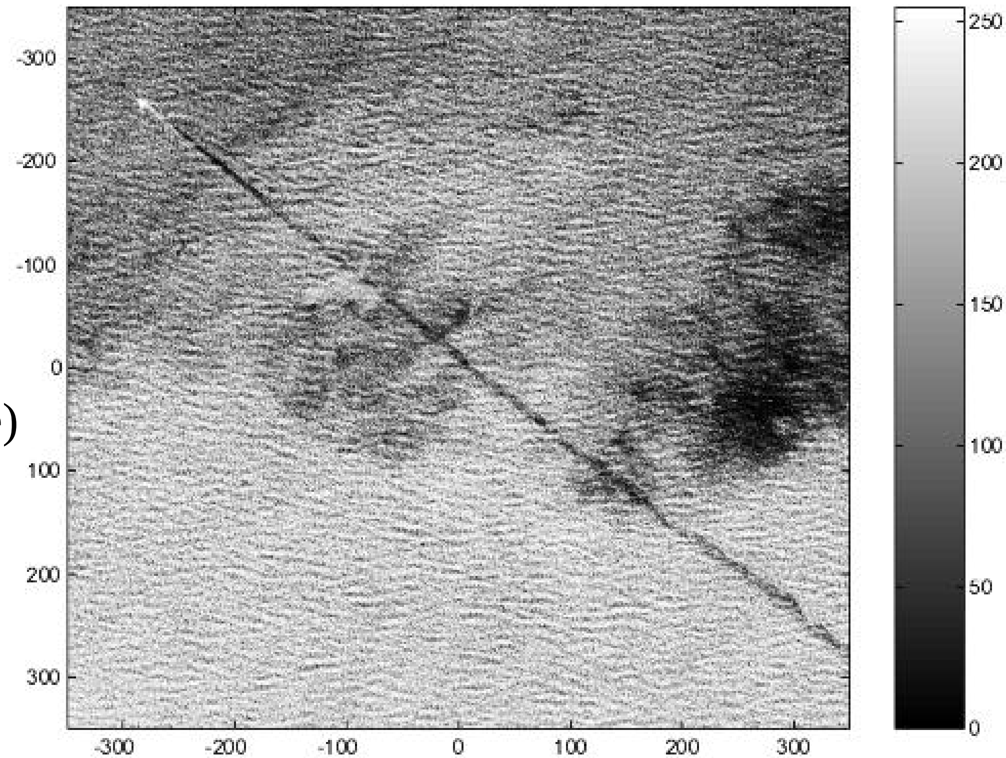
↳moving ship

↳dark turbulent wake (17 miles)

❍256 gray levels (0: black, 255: white)

❍Image size: $698 \times 698$

❍Variation coefficient: 0.277



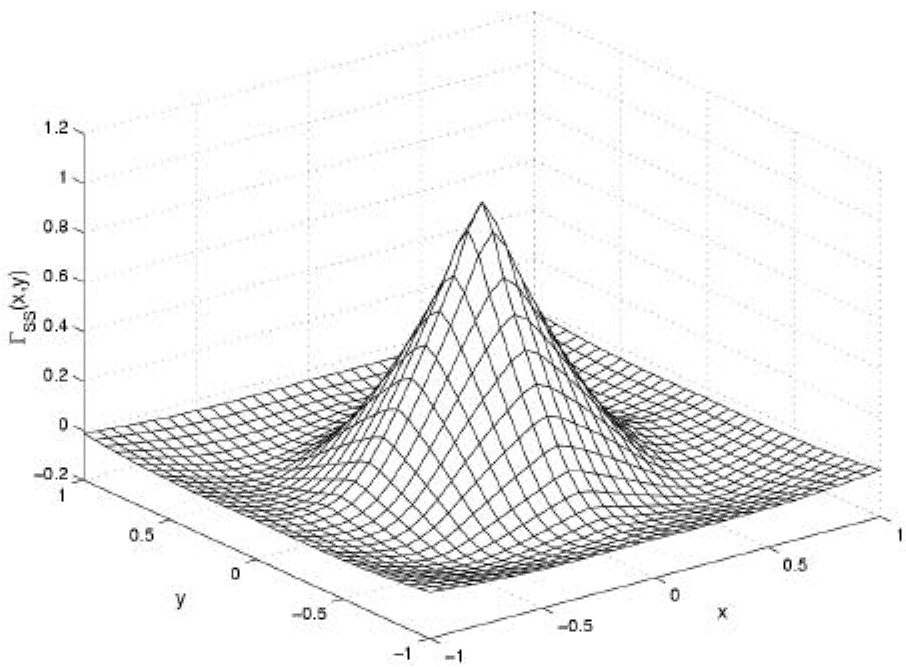

❍Difficulty: dark patches in the upper right corresponding to smooth area of low wind

# LINEAR FEATURE DETECTION IN SAR IMAGES

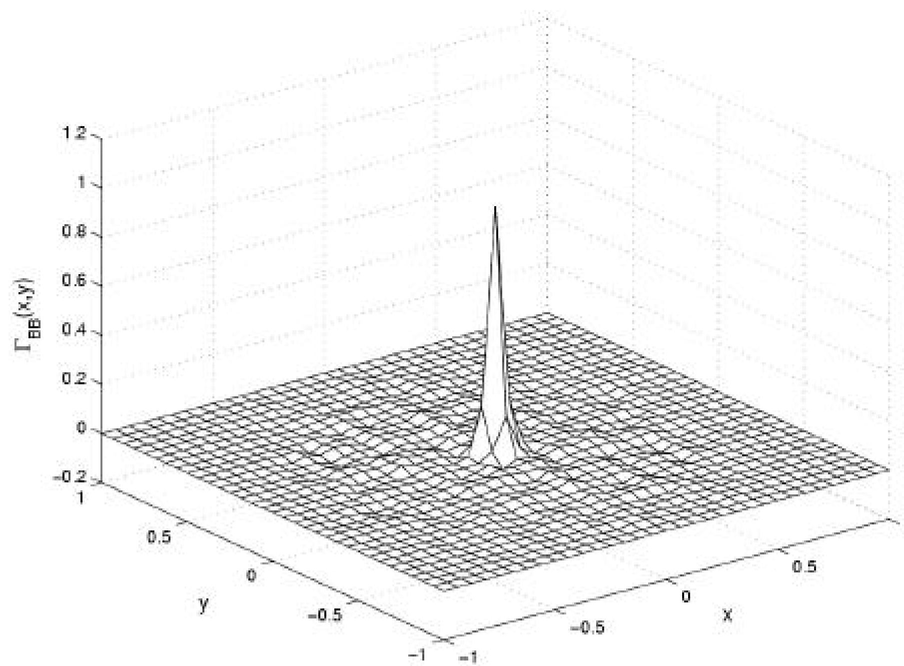
## Signal and noise auto-correlation functions

❍ *a priori* knowledge of the signal and the noise auto-correlation functions

$\Rightarrow$ determination of normalized auto-correlation models




Signal auto-correlation function




Noise auto-correlation function

# LINEAR FEATURE DETECTION IN SAR IMAGES

## Interpolation-filtering of the SIR-C/X-SAR image

❍ Rotation angle: $35^o$

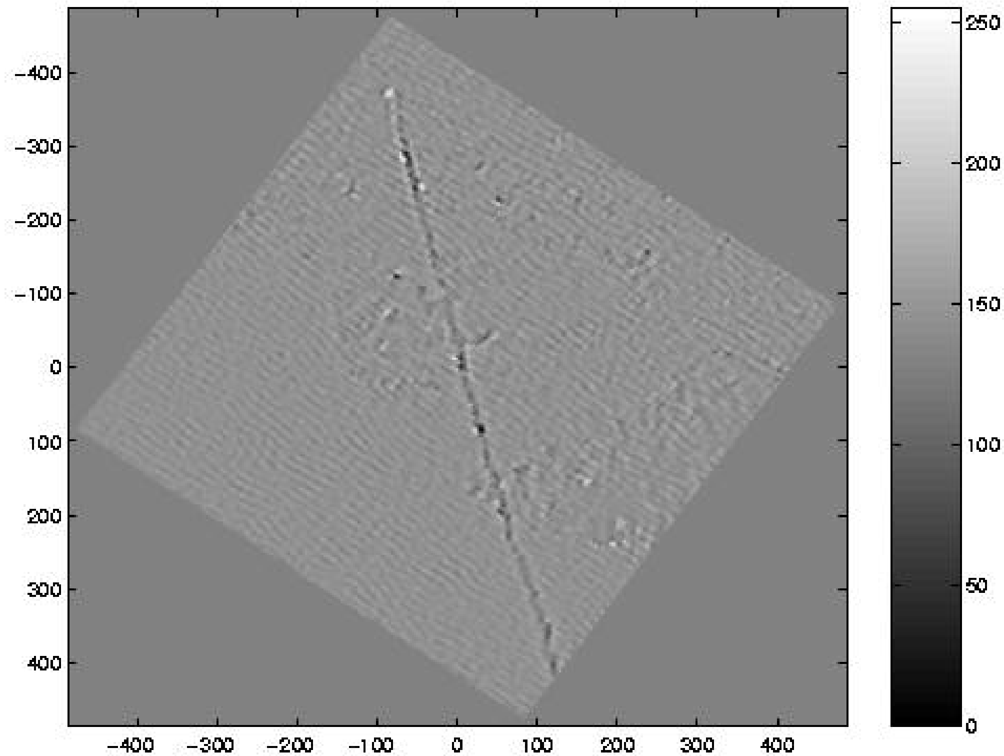
❍ Number $Q$ of basis functions:

↳ approximately 13 for the wake

↳ near 1 for the rest of the image

❍ Image size: $973 \times 973$

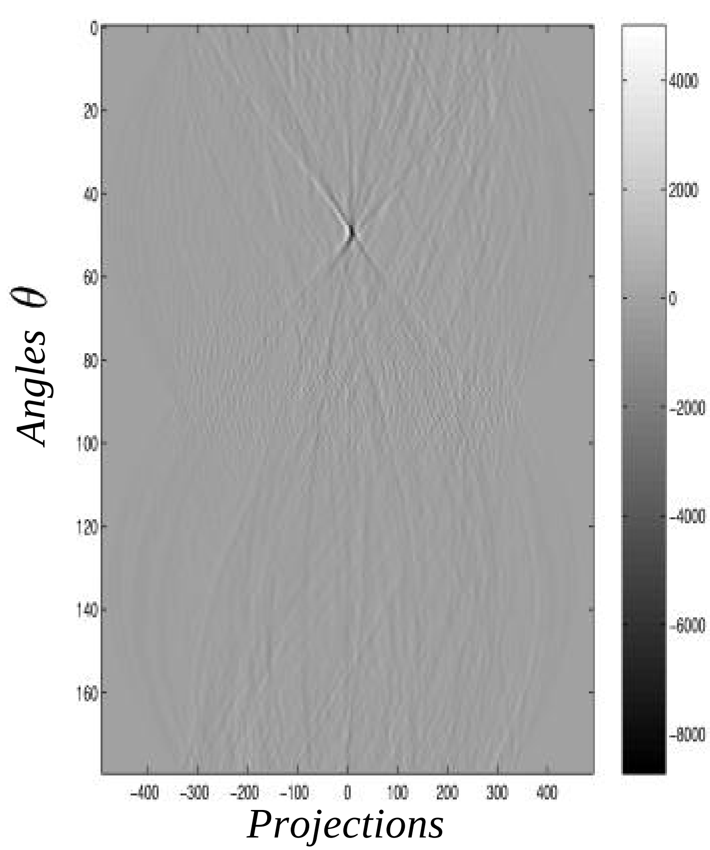
❍ Variation coefficient: 0.016



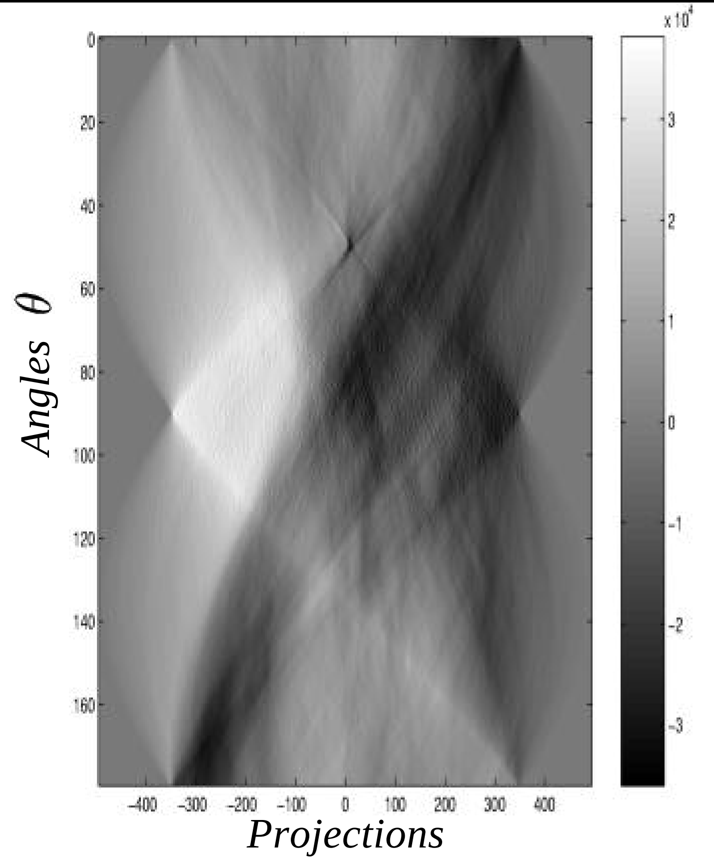

SIR-C/X-SAR image in reference system $\Re_{35}$

## LINEAR FEATURE DETECTION IN SAR IMAGES

**Radon domain displayed as image**



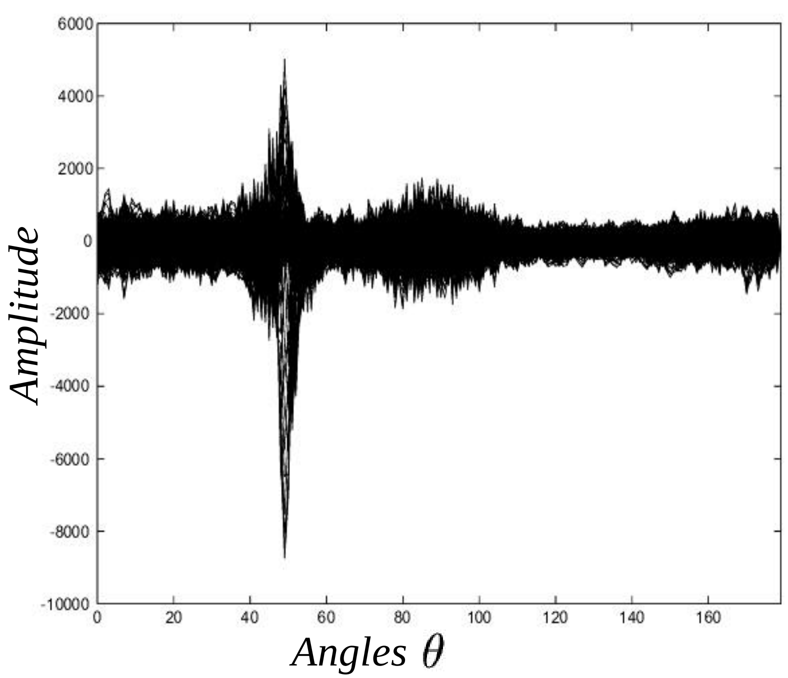

Our processing



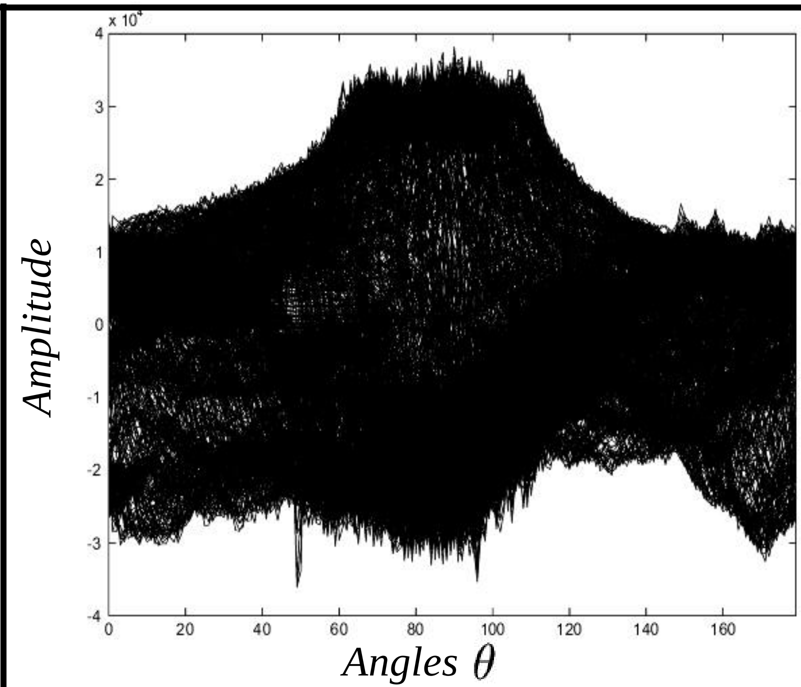

Classical processing

↳ Trough corresponding to the wake localized near $51^o$

## Radon domain displayed as graph




Our processing




Classical processing

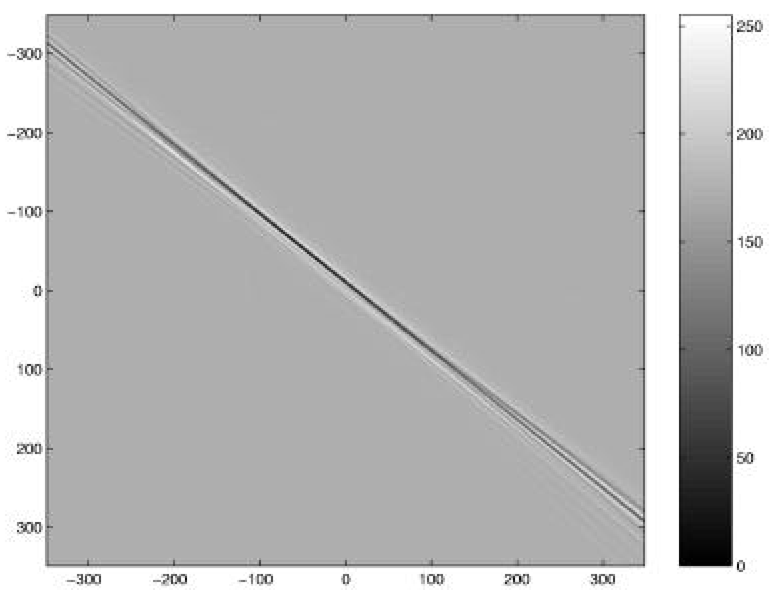
➯No ambiguity about the presence of a ship wake with our processing

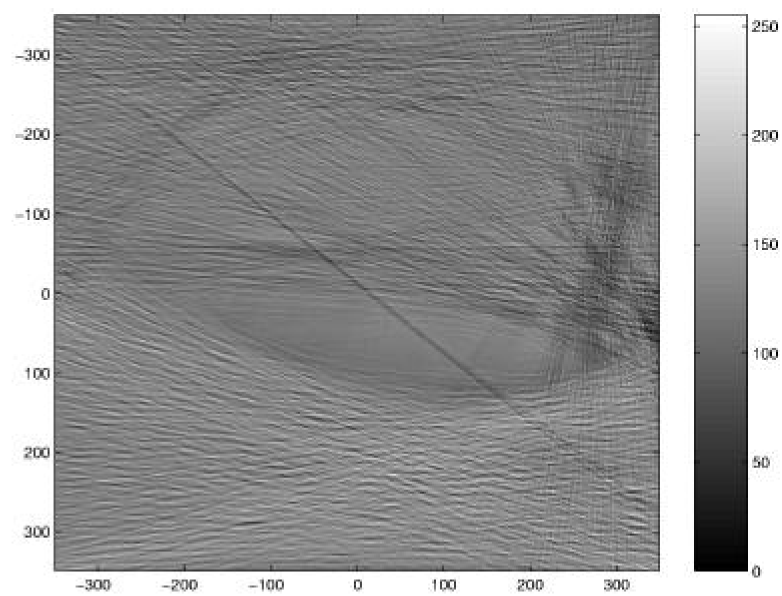
$\Rightarrow$ detection by simply using a threshold contrarily to classical approach

# LINEAR FEATURE DETECTION IN SAR IMAGES

## Reconstructed image using the transform domain

↳Inverse Radon transform applied to the transform domain raised to the power of 3

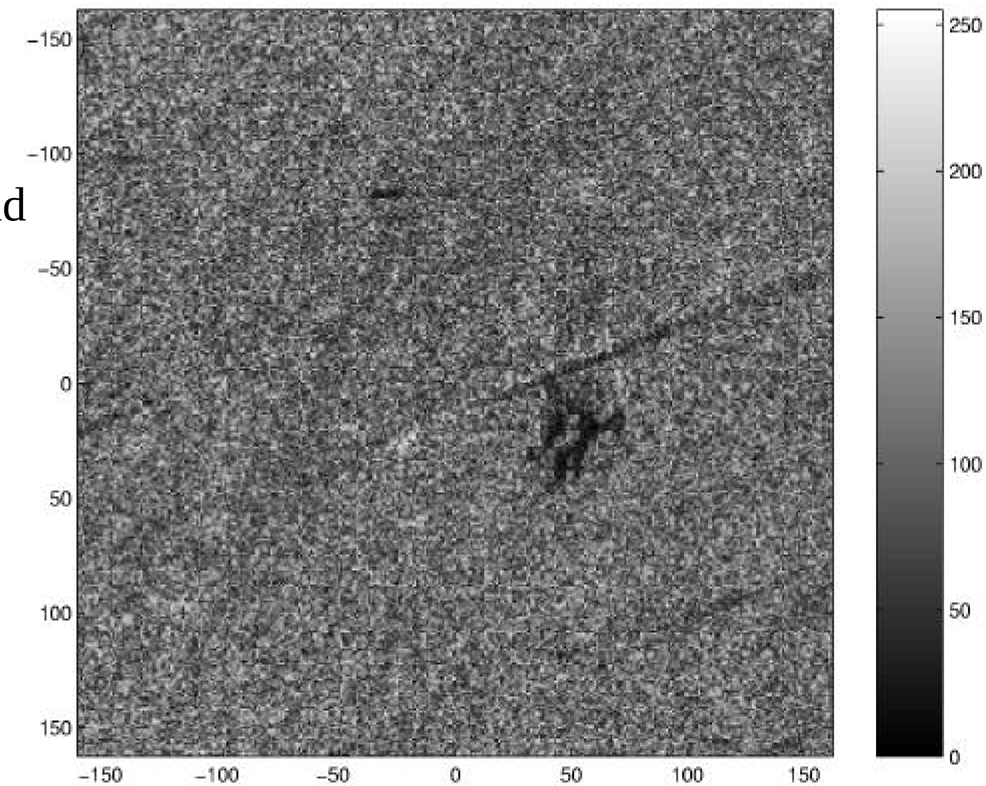



| Our processing<br>Variation coefficient: 0.002 | Classical processing<br>Variation coefficient: 0.145 |
| --- | --- |

# LINEAR FEATURE DETECTION IN SAR IMAGES

## ANOTHER SAR IMAGE




❍ERS SAR image

➩ship pixels replaced by mean background

➩dark turbulent wake

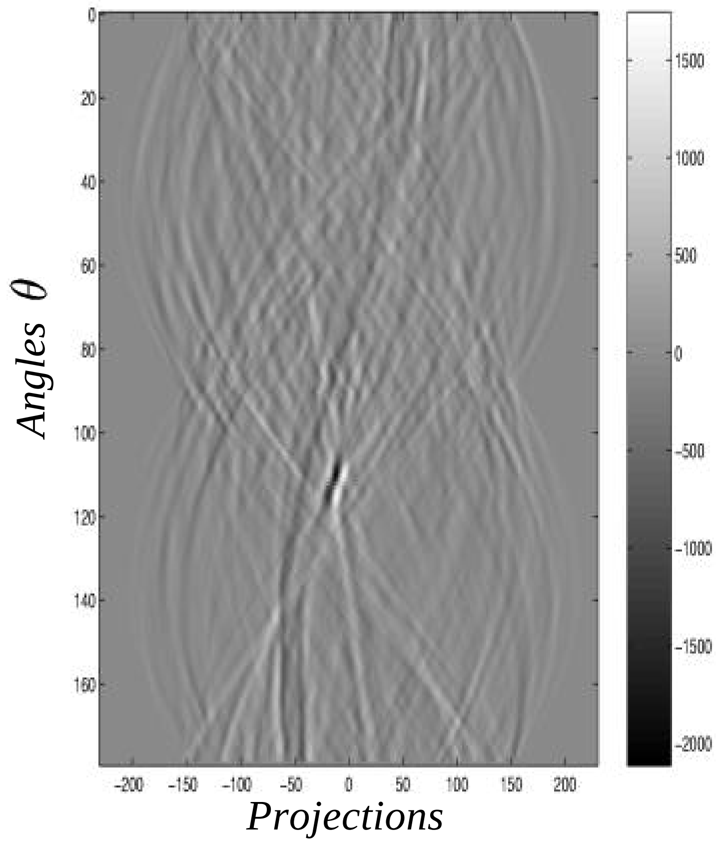
❍256 gray levels (0: black, 255: white)

❍Image size: $325 \times 325$

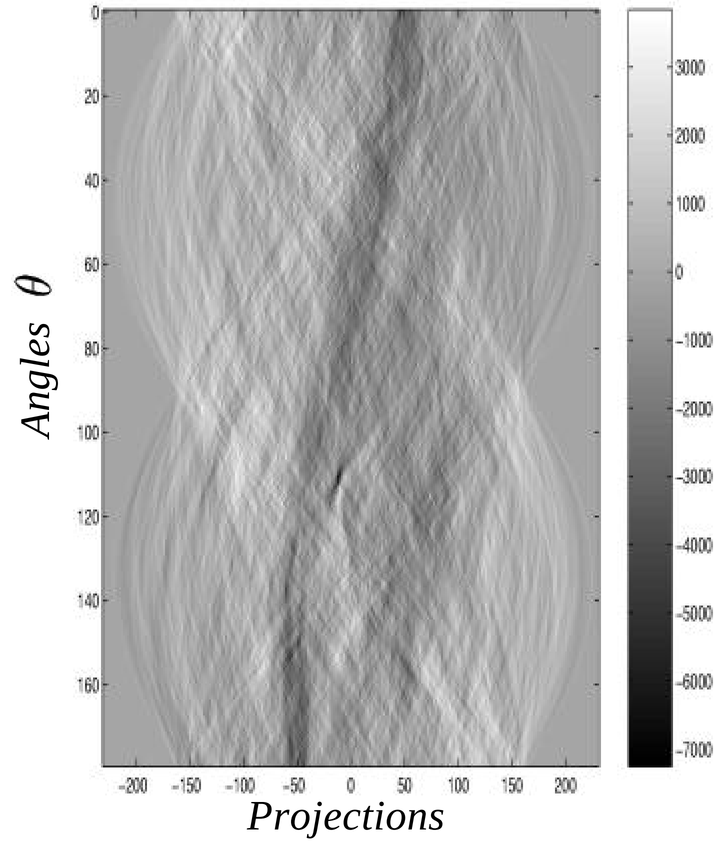
❍Difficulty: dark patch near the wake (slick oil)

# LINEAR FEATURE DETECTION IN SAR IMAGES

**Radon domain displayed as image**




Our processing




Classical processing

↳ Trough corresponding to the wake localized near $115^o$

# LINEAR FEATURE DETECTION IN SAR IMAGES

## CONCLUSION

- New processing for ship wakes detection
  - SAR image Radon transform
  - original contribution: taking into account the speckle for image interpolation
- Better detection with lower probability of false alarm or no detection
- Future work: extension of this method to the localized Radon transform